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Image upconversion, a low noise infrared sensor?

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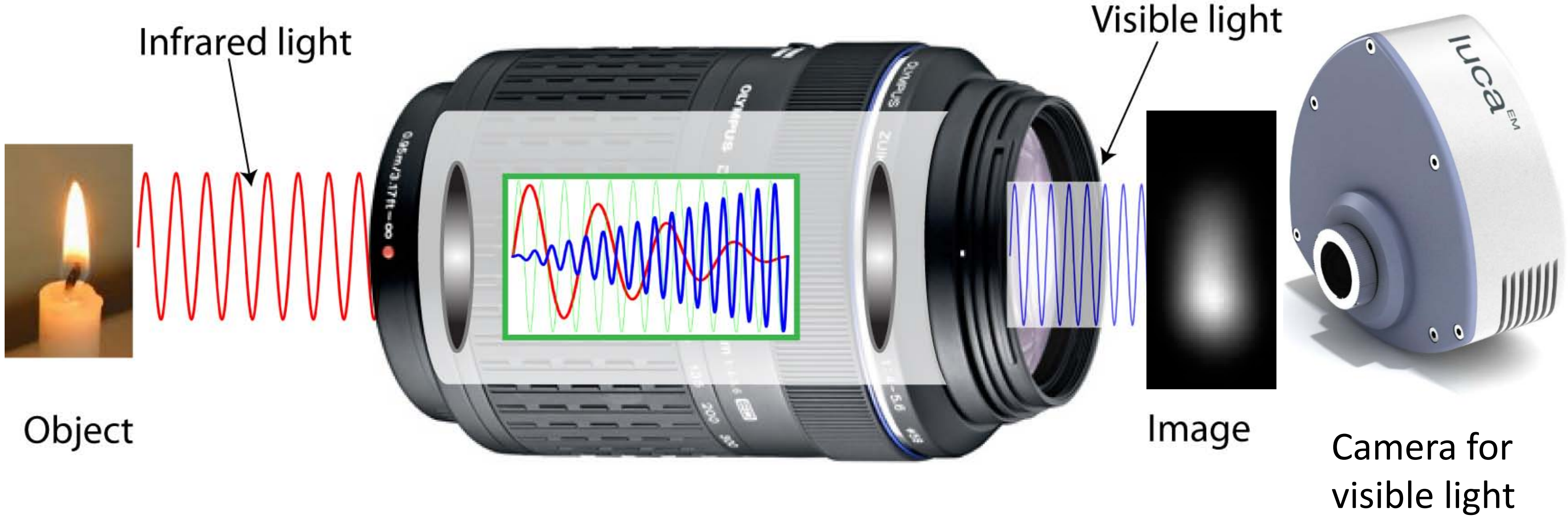
Outline

- Concept
- Existing infrared image sensors
- Wavelength conversion fundamentals
- Discuss noise sources in conversion process
- Present measurement of noise characteristics
- Discuss sensitivity limit
- Outlook and conclusions

The Concept


Infrared light
Visible light
Object
Image
Camera for
visible light

Exisiting infrared imaging devices

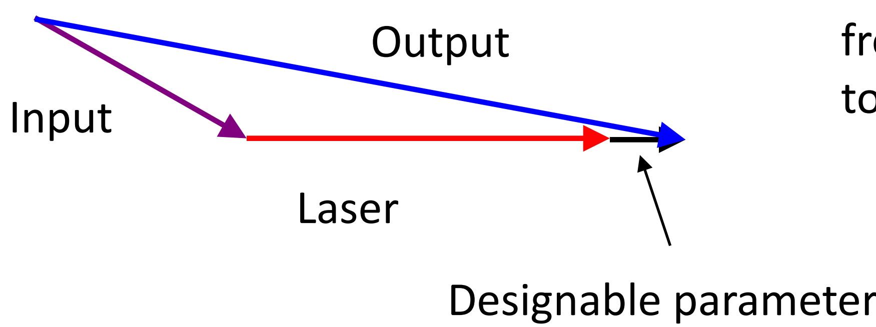
- Microbolometers (cooled and un-cooled)
- Low bandgap semiconductor (InSb, MCT)
- Common features: Large dark noise, particularly for un-cooled devices. Wide bandwidth acceptance. Well suited for thermal imaging

Wavelength conversion fundamentals

Energy conservation:

$$\omega_3 = \omega_1 + \omega_2 \Leftrightarrow \frac{1}{\lambda_3} = \frac{1}{\lambda_1} + \frac{1}{\lambda_2}$$

Momentum conservation:



Non-linear process?

$$I_3(\omega_3) = \eta I_2(\omega_2) I_1(\omega_1)$$

$$I_3(\omega_3) = k I_1(\omega_1)$$

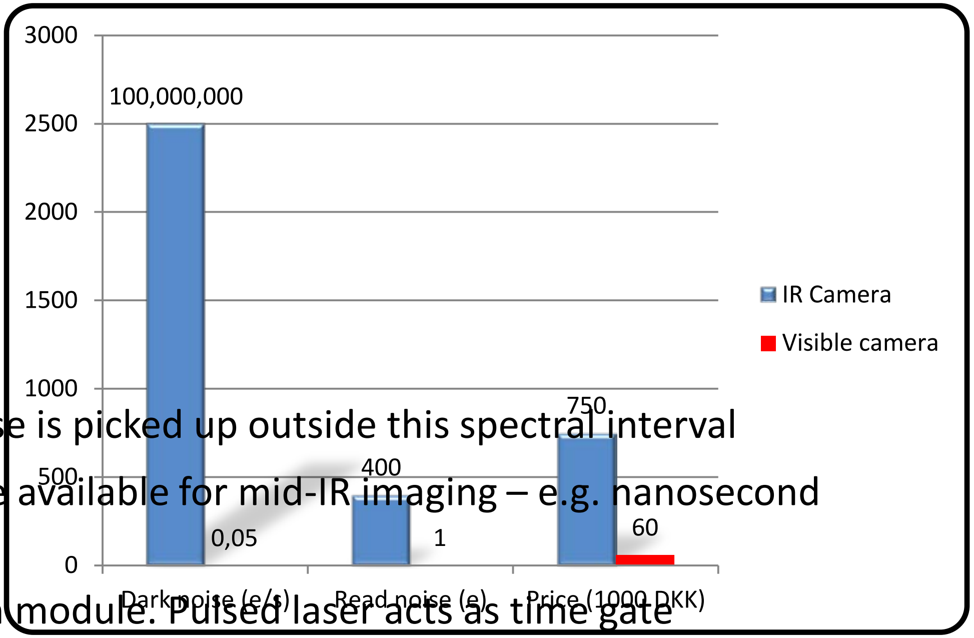
Output is proportional to input

Huge dynamic range,
from 0.1 photons per second
to 10^{18} photons per second

Why change the wavelength

Reason 1. Signal to noise and price

- Infrared cameras have high dark noise and read noise. They need extreme cooling for optimal performance



Reason 2. Added functionality:

- Spectral acceptance can be tailored, no noise is picked up outside this spectral interval

- Features existing in silicon camera are made available for mid-IR imaging – e.g. nanosecond imaging is possible

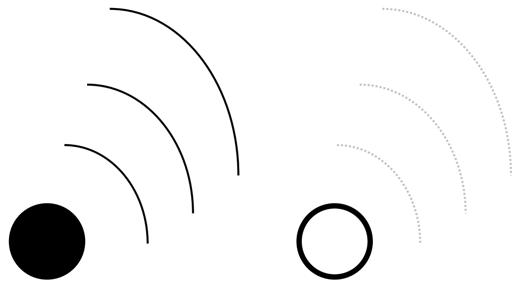
- Time-gating can be built into the conversion module. Pulsed laser acts as time gate

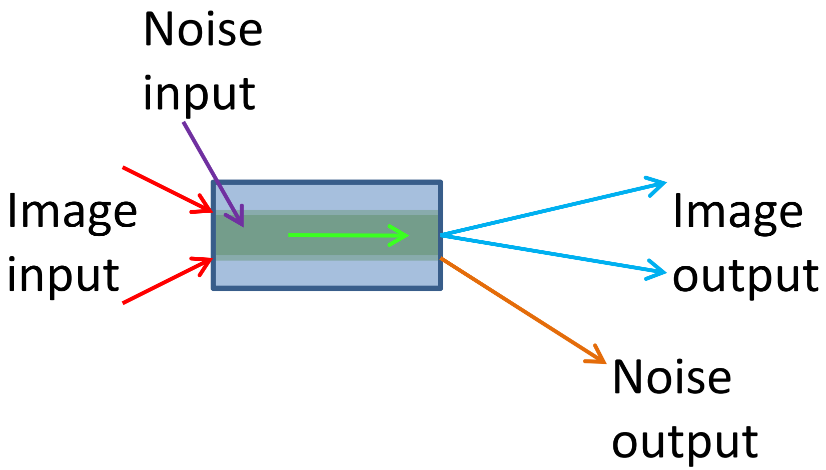
Reason 3. Spectral analysis:

- Spectral information exists even after upconversion. Can now be resolved using visible optics/spectrometers

Noise free conversion! How come?

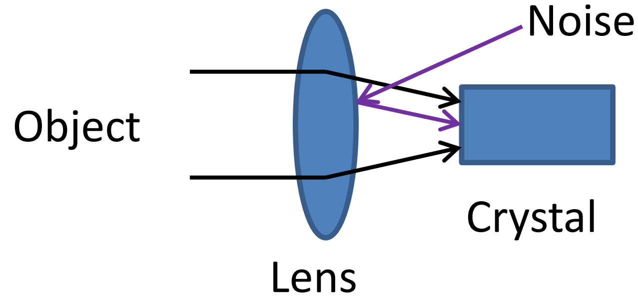
- Detection in transparent medium!
- No input – No output.
- Blackbody (thermal) radiation is only emitted by absorbing media. Transparent media cannot absorb or emit (thermal) radiation
- The wavelength mixing occurring inside the non-linear crystal is governed by the phase-matching conditions, and energy/momentum conservation

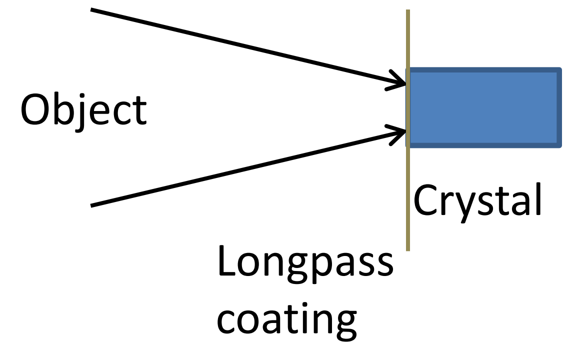




Noise free? Really?

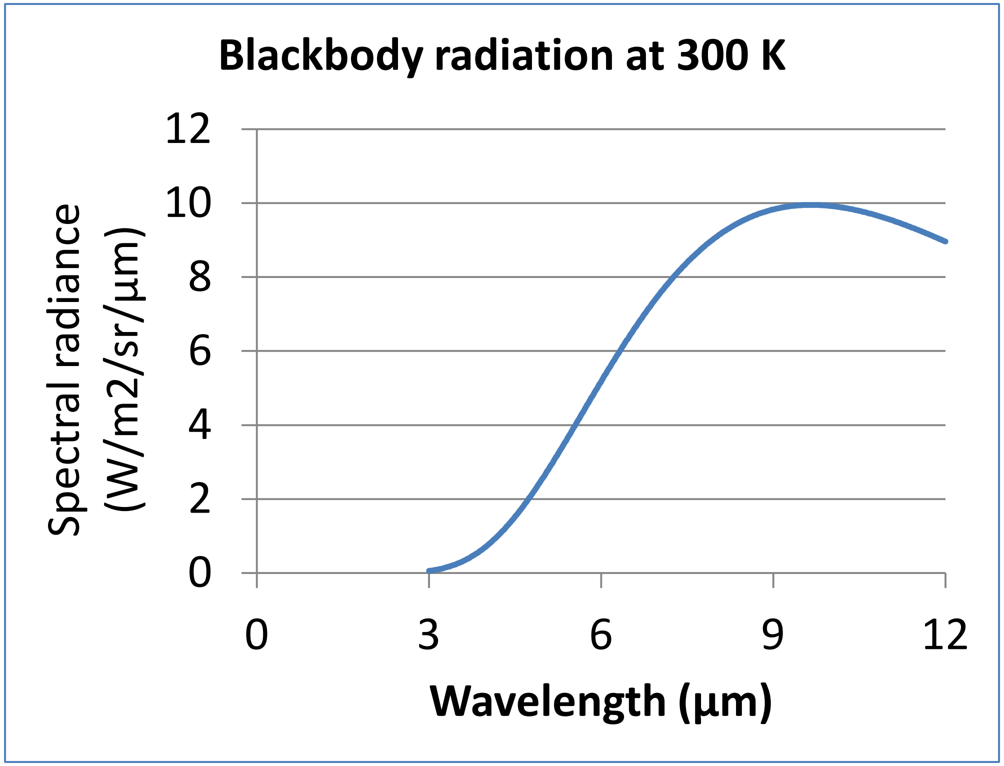
- *Wont there at least be reflections from optics etc. in front of the camera system?*
- The system can actually work without **any** optics in front of the nonlinear crystal. No focusing optics are required, since we upconvert infinity corrected light. Filtering can be done in crystal input surface coating (longpass filtering allowing only IR to pass through coating).
- Size of image depends on crystal parameters. Camera viewing angle is ~12° in current setup



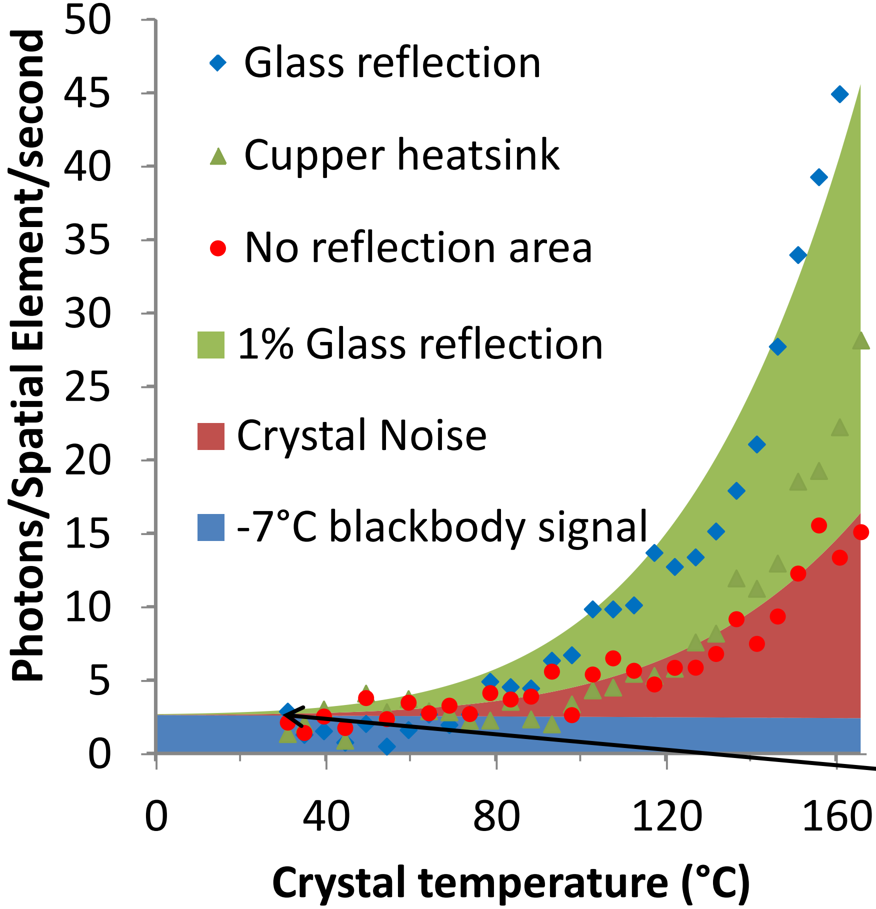


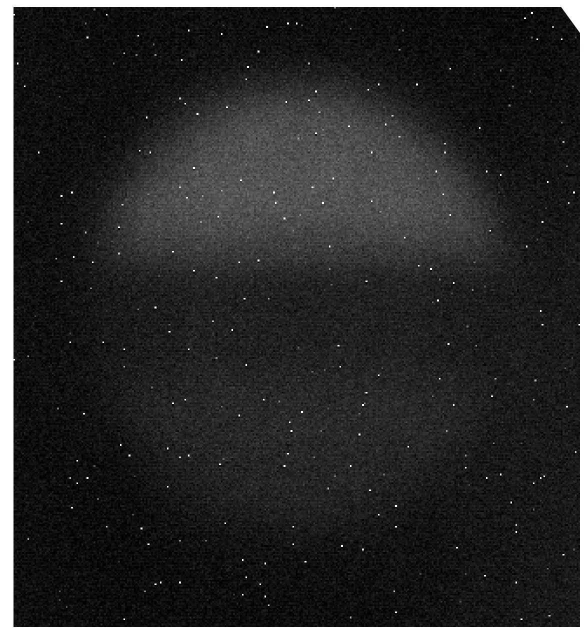
But the crystal is not transparent?

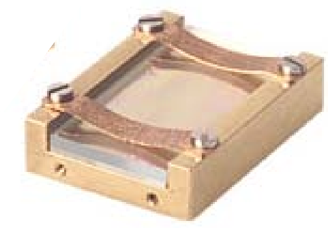
- True. Lithium Niobate has a measureable absorbance/emissivity. It is ~0.005/cm at 3 μm.
- The crystal generated noise is thus on the order of the signal from an object at that temperature multiplied with the emissivity



Noise generated by crystal and mount

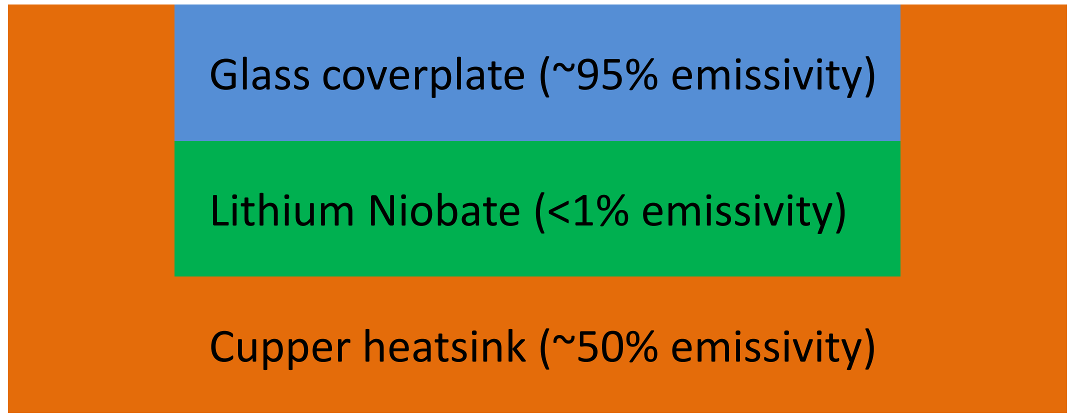


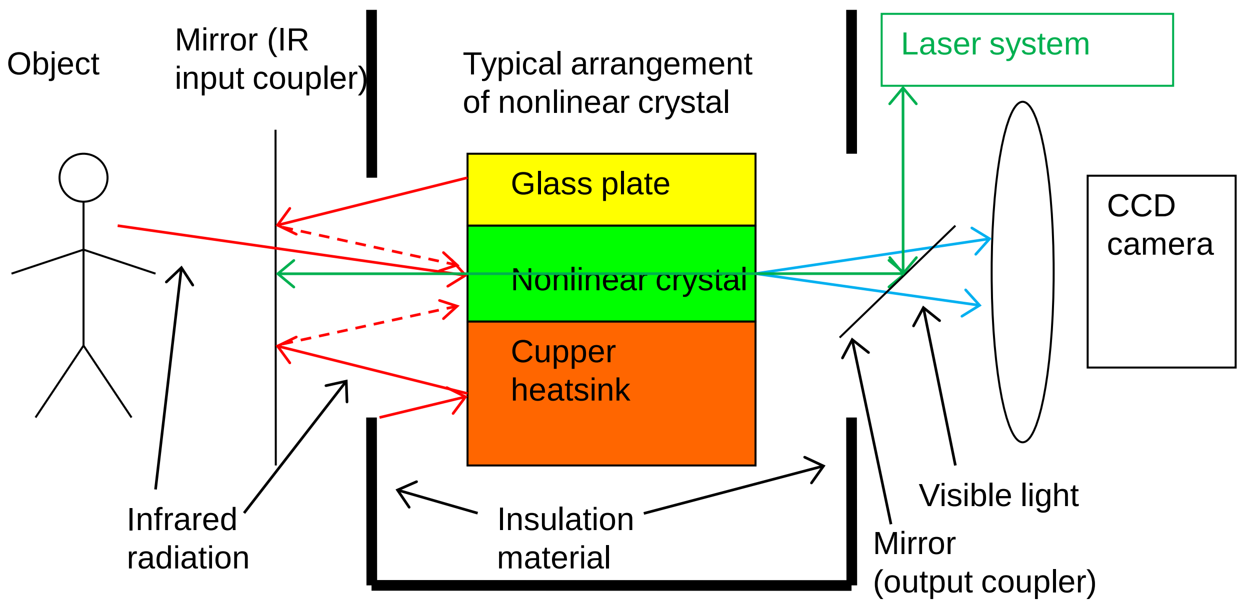




0.15 Photons/Spatial Element/second
0.008 e^{-}/pixel/s
That is 1 billion times less than IR cameras

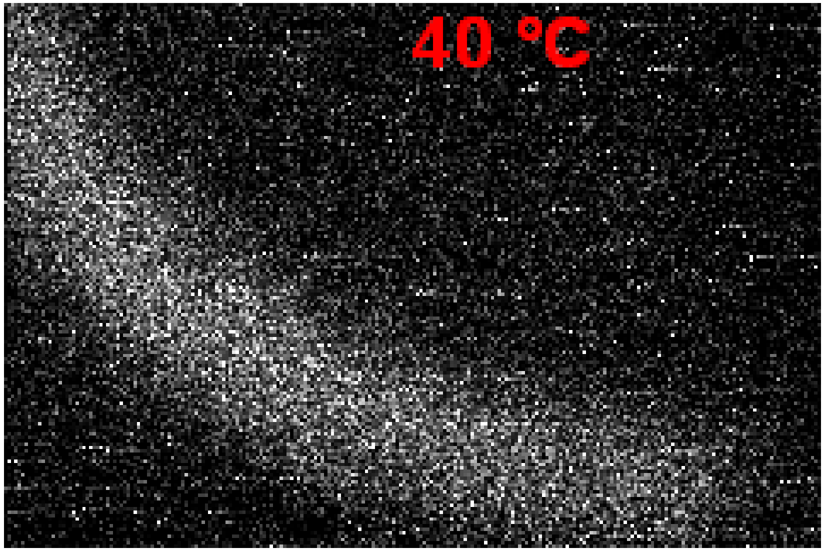
Crystal surroundings





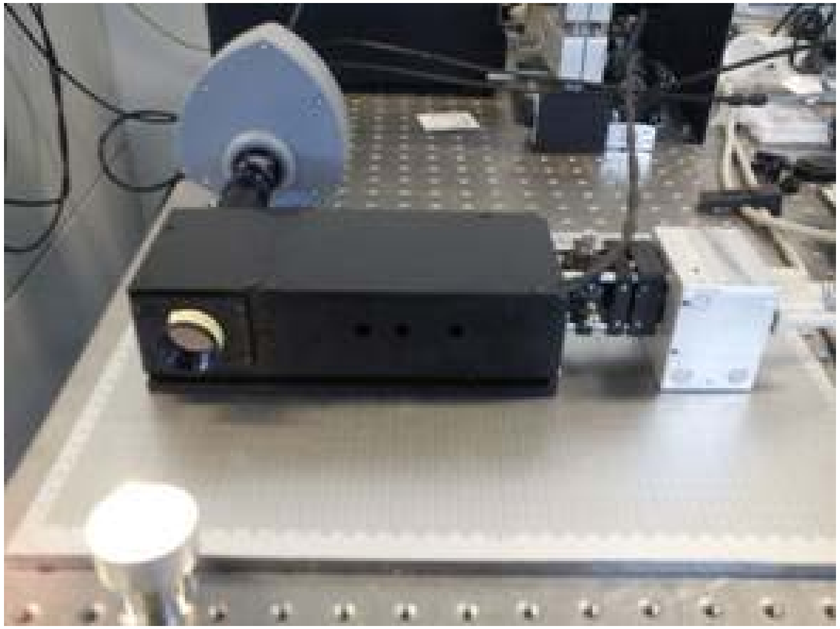
Single photon mid-IR imaging!

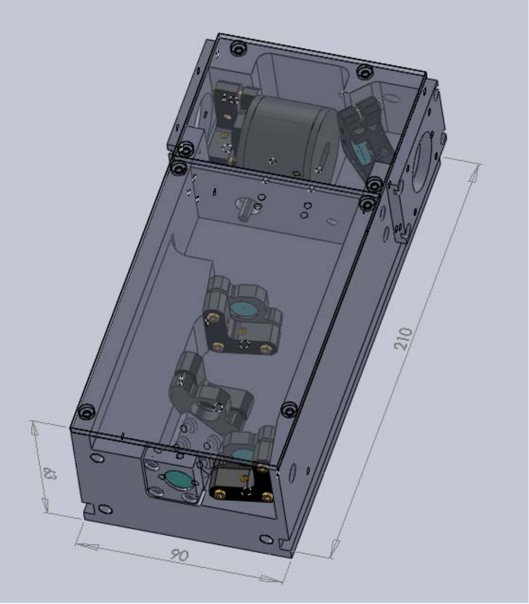
- Imaging a thermal blackbody at different temperatures. Each frame in video acquired over 30 s.
- Intensity varies from
- 2 photons/pixel/s (40 °C) to 0.1 photons/pixel/s (-10 °C)
- 30 seconds*0.1*20% QE of camera gives ~0.5 detected photon per pixel for lowest temperature

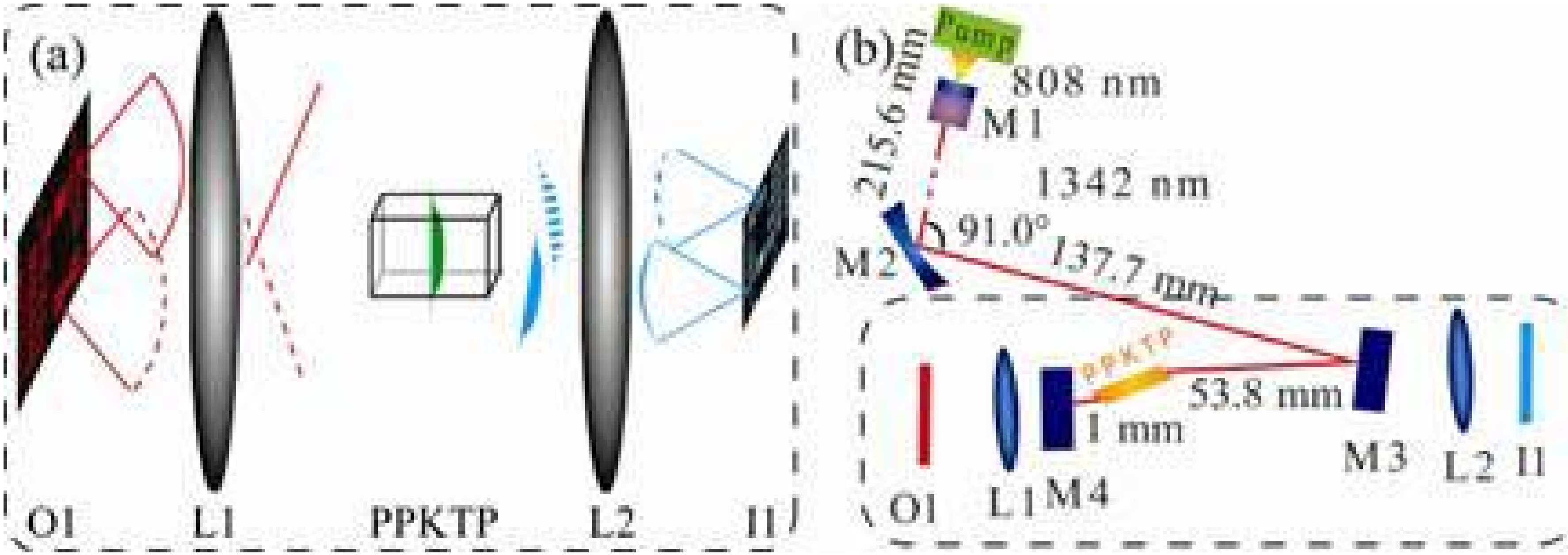


Portable!

- Low noise? YES!
- Thank you for your attention!






(a)
O1
L1
PPKTP
L2
I1
(b)
Pump
808 nm
M1
215.6 mm
1342 nm
91.0°
137.7 mm
M2
PPKTP
53.8 mm
1 mm
M3
O1
L1
M4
L2
I1